DEVELOPMENT OF A SENSOR FOR ESTIMATION OF THE RATE OF CORROSION OF WELDED METAL STRUCTURE UNDER ATMOSPHERIC CONDITIONS

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A two-electrode sensor with co-surface electrode position was developed for measurement of the instantaneous rate of corrosion of structural steels and welded joints in thin electrolyte films. Performance of the sensor was demonstrated for measurement of the rate of atmospheric corrosion at different temperatures, 100 % air humidity with and without moisture condensation. It was established that under conditions simulating the atmospheric ones the developed sensor can be used to measure the corrosion rate in the $1\cdot10^{-6}$–10 mm/year range.

Keywords: *corrosion rate sensor, atmospheric corrosion of welded metal structures, condensation of moisture on metal surface, polarisation resistance method*

Atmospheric corrosion is the most common type of corrosion, as about 80 % of metal structures operate under the atmospheric conditions. Atmospheric corrosion of metals is mainly of an electrochemical nature and occurs in thin films of the moisture, which is condensed on the metal surface. Corrosion in atmosphere is a long-duration process. The time to complete fracture of a metal structure is from 5 to 16 years. However, it would be wrong to think that the process of corrosion in atmosphere is always slow and occurs at a lower rate than when metal is immersed into the bulk of electrolyte. While the mean rate of corrosion in sea water is i_c = 0.10–0.15 mm/year, the rate of corrosion of piles in a zone of cyclic wetting, e.g. in the Caspian oil fields, is 0.5–0.6 mm/year. The rate of atmospheric corrosion (i_c, mm/year) in living and industrial premises is given below [1]:

kitchen and bathroom	0.0025–0.0100
laundry	0.0075
bleachery	0.0430
sulphuric acid factory	0.0480
paper mill	0.0680
locomotive depot	0.0800
etching shop at metallurgical works	above 0.450

Corrosion of the unprotected surface of steel and its welded joints in atmosphere depends on the climatic conditions of specific surroundings. The main causes of atmospheric corrosion are humidity and temperature of air, temperature differences, wetting–drying cycles, and presence of sulphur dioxide (industrial atmosphere) or sodium chloride (sea atmosphere) in air.

The rate of corrosion during the first year of operation of welded metal structures is 0.19 mm/year, which is the upper limit for the most aggressive atmospheres (category C5) according to standard ISO 12944–2. Corrosion may occur at low humidity values in the presence of contaminants or hygroscopic salts.

It is a known fact that the key factor inducing the atmospheric corrosion is water [1], which leads to formation of a moisture film on the surface of metal. At a relative air humidity of no more than 60 % no traces of moisture are fixed on the metal surface. In this case corrosion occurs by the chemical mechanism.

At a relative air humidity of 60–70 %, which is called critical, the moisture condensation process begins, and a thin continuous adsorption water film forms on the metal surface. Critical humidity of the industrial atmosphere is 60 % on the average. The rate of the atmospheric corrosion considerably increases at a relative humidity that is higher than the critical one.

This important fact was first demonstrated by Vernon in a series of his classical experiments [1]. He demonstrated that corrosion in clean air at a relative humidity below 100 % occurs at a rate of not more than 0.001–0.002 mm/year, whereas the presence of an insignificant concentration of such impurities as sulphur dioxide may cause a 100 times increase in the rate of corrosion even at the absence of visible traces of moisture. For this it is enough that the relative humidity exceeds some critical (even comparatively low) value, which depends on the nature of the atmospheric pollution, but is 70–80 % at the presence of sulphur dioxide. If humidity is below the critical value, the rate of corrosion is lower than 0.001 mm/year even in the polluted air.

It is well known that the thin film on the metal surface affects the course of the corrosion processes, while the rate of corrosion depends in a certain way on the thickness of this film. Thin films can be of two types: adsorption films that are formed at a relative air humidity of 60 to 70 %, and phase films that are visible to the naked eye and formed at an air humidity close to 100 %, which may be or may not be accompanied by the condensation of moisture on the surface.

At present no procedure is available for monitoring of durable welded metal structures under the atmos-

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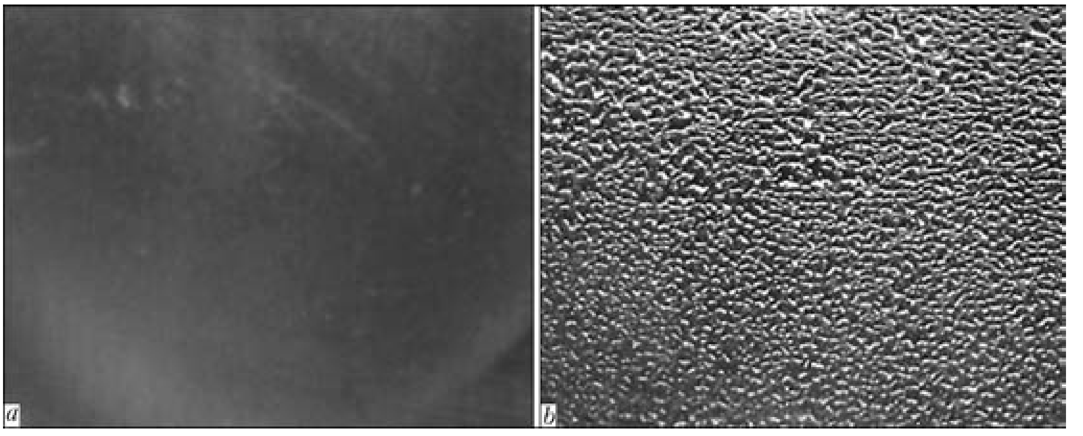

Figure 1. Appearance of the moisture film formed on the surface of steel St3 and its welded joints at T = 24 °C without moisture condensation (*a*) and at T = 50 °C with moisture condensation (*b*)

pheric corrosion conditions. Development of such a procedure is impossible without development of reliable and unfailing corrosion control means, i.e. sensing devices or sensors with a high sensitivity level, which allow measuring the instantaneous rate of corrosion over a period of a diurnal cycle on durable facilities, such as storage or industrial rooms, including the new safe confinement at the Chernobyl NPP.

The two-electrode sensor with co-surface position of electrodes, the sensing element of which is made from steel St3, was developed to measure the instantaneous rate of corrosion of structural steels and their welded joints in thin electrolyte films. To obtain more reliable data on the rate of corrosion, it is planned that the sensing element of the sensor will be made from the same material as the material of a metal structure. To increase the accuracy of measurements, the sensing element is placed on the anodised plate, with the help of which the sensor is secured to the metal structure being monitored. The operation of the sensor is based on the polarisation resistance method, the theoretical principles of which are described in study [2].

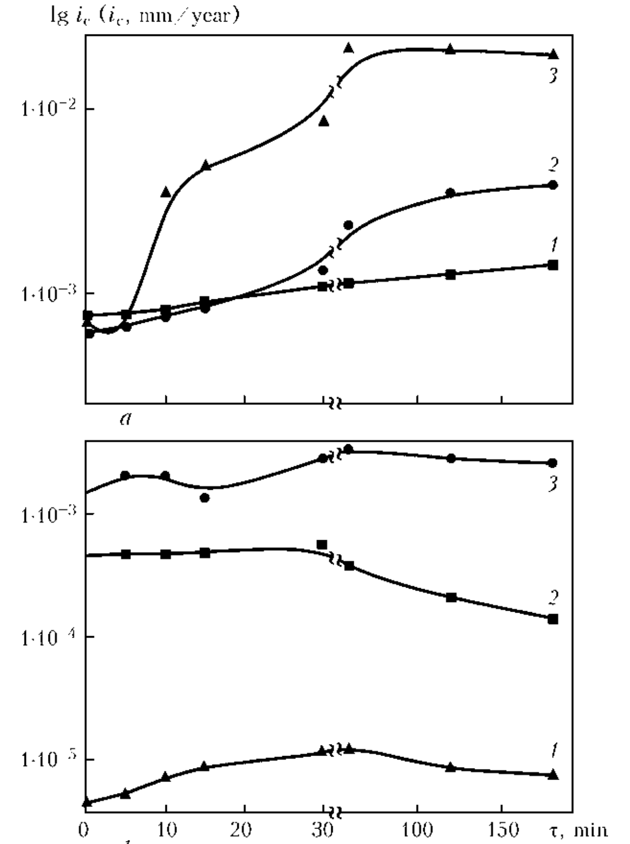

Figure 2. Kinetics of corrosion rate i_c on structural steel St3 under conditions simulating the atmospheric ones with (*a*) and without (*b*) moisture condensation on the metal surface at T = 24 (*1*), 50 (*2*) and 70 (*3*) °C, which was determined with the help of the corrosion rate sensor

Specifications of the sensor

Range of measurement of atmospheric corrosion rate, mm/year .... $1\cdot10^{-5}$–5
Measured polarisation resistance, Ohm .... 10^2–10^7
Service conditions:
temperature, °C .... −40 – +70
relative air humidity, % 80–100
Measurement error, % .... no more than 20

Investigations were conducted to study the peculiarities of corrosion of carbon steel St3 and its welded joints under conditions simulating the atmospheric ones at an air temperature of 24, 50 and 70 °C, and at a relative humidity of 100 %. For this the corrosion rate sensors and samples of the welded joints were placed horizontally to let the moisture films form on their surfaces. The measurements were made under the temperature-controlled conditions. The investigations were carried out by creating the atmospheric conditions, under which the moisture condensed on the metal surface, but the condensation of the moisture on the surface was not yet completed, and then the thickness of the formed film was estimated (Figure 1).

Rate of corrosion of structural steel and its welded joints (i_c, mm/year) determined by the polarisation resistance method under conditions simulating the atmospheric ones

T, °C	With moisture condensation	Without moisture condensation
24	$1.4\cdot10^{-3}$	$1.4\cdot10^{-3}$
50	$3.9\cdot10^{-3}$	$2.3\cdot10^{-4}$
70	$2.0\cdot10^{-2}$	$7.5\cdot10^{-6}$

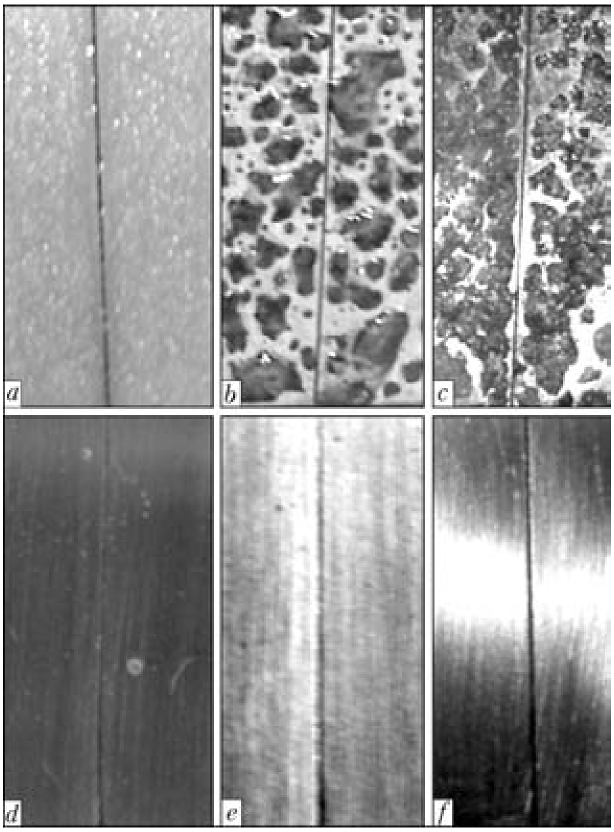

Figure 3. Appearance of the surface of sensors after exposure (t = = 3 h) to conditions simulating the atmospheric ones with (a–c) and without (d–f) moisture condensation on the sensor surface at T = 24 (a, d), 50 (b, e) and 70 (c, f) °C

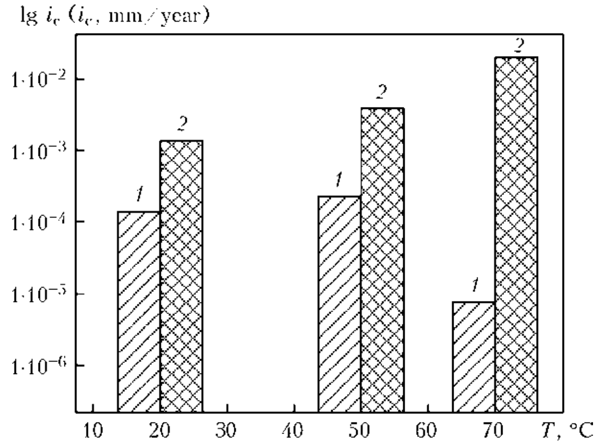

Figure 4. Dependence of i_c of structural steel St3 on temperature under conditions simulating the atmospheric ones with (*1*) and without (*2*) moisture condensation on the sensor surface, determined by using the corrosion rate sensor

It was determined that a very thin film from 0.6 to 3.0 μm thick formed on the sample surfaces at a temperature of 24 °C for 20 min under the moisture condensation conditions (see Figure 1, *a*). At $T > 40$ °C under the moisture condensation conditions the visible phase layers of moisture and water droplets formed on the samples surfaces. Thickness of the moisture layer ranged from 17 to 45 μm (see Figure 1, *b*).

The instantaneous corrosion rate was estimated under laboratory conditions simulating the atmospheric ones (for 3 h). The results obtained are given in the Table and in Figures 2–4.

It can be noted as a result of analysis of the obtained data that the rate of corrosion of steel St3 and its welded joints in thin moisture films grew with increase in temperature of the humid air because of intensification of the process of moisture condensation and formation of moisture layers of different thicknesses. Corrosion in these layers occurred by different mechanisms: in layers less than 30 μm thick it occurred by the diffusion mechanism, and in layers more than 30 μm thick — by the convection mechanism [1, 2].

At T = 24 °C the moisture condensation was slower than at a higher temperature. In this case the moisture film from 0.6 to 3.0 μm thick formed on the metal surface. Corrosion was of a continuous character and occurred at a rate of no more than 0.005 mm/year (Figure 2, *a*, curve *1*; Figure 3, *a*).

Because of formation of a non-uniform layer of moisture on the surface of the sensors, corrosion acquired a hot-spot character with increase in temperature (Figure 3, *b*, *c*). The highest corrosion rate was fixed under the moisture droplets. Increase in the local corrosion rate was promoted by the formed corrosion products, which were hygroscopic in their properties and kept the moisture on the sensor surface.

The rate of corrosion of steel St3 and its welded joints at the absence of the condensation of moisture on the sensor surface also grew with increase in temperature from 24 to 50 °C, and was 0.00014 mm/years at T = 24 °C (Figure 2, *b*, curve *1*; Figure 3, *d*) and 0.00023 mm/year at T = 50 °C (Figure 2, *b*, curve *2*; Figure 3, *e*). These values of the rate of corrosion evidenced that metal behaved as the «absolutely corrosion-resistant one» according to the five-point scale of corrosion resistance [2]. Further increase in temperature to 70 °C led to decrease in the rate of corrosion (Figure 2, *b*, curve *3*; Figure 3, *f*). This phenomenon can be explained by heating of the sensor and, as a result, drying of the formed phase layer, which probably led to a change in the corrosion mechanism from the electrochemical to chemical one, and to a substantial decrease of the rate of corrosion.

It is planned to continue the research efforts on investigation of atmospheric corrosion of structural steels and their welded joints by the polarisation resistance method on the laboratory scale and under service conditions at different temperatures and at the air humidity close to the critical one. It is intended to develop systems for continuous monitoring of the corrosion state of welded metal structures.

CONCLUSIONS

1. Peculiarities of corrosion of carbon steel St3 and its welded joints under conditions simulating the atmospheric ones (air temperature 20, 50 and 70 °C, and relative humidity 100 % with and without moisture condensation) were investigated. It was estab-

lished that in thin moisture films the rate of corrosion grows with increase in temperature of the humid air because of intensification of the moisture condensation process and formation of the layers of different thicknesses.

2. Thickness of the moisture film formed on the metal surface under different conditions was estimated. It was shown that thickness of the moisture layer on the sensor surface at a temperature of 24 °C under the moisture condensation conditions was 0.6–3.0 μm, and increased to 17–45 μm with increase in temperature to more than 40 °C.

3. Performance of the sensor for measuring the rate of atmospheric corrosion at different temperatures, air humidity of 100 % with and without moisture condensation was studied. It was determined that the sensor can measure the rate of corrosion over a range of $1\cdot10^{-6}$–10 mm/year.

1. Rosenfeld, L.I. (1960) *Atmospheric corrosion of metals*. Moscow: AN SSSR.
2. Chviruk, V.P., Polyakov, S.G., Gerasymenko, Yu.S. (2007) *Electrochemical monitoring of man-made environments*. Kyiv: Akademperiodyka.

NEWS

NEW INTERACTIVE ELECTRIC WELDING LABORATORY

PWI RC SKAE completed development of a new facility for welder's training during the real process. Arc welder's trainer (DTS-06) is designed for on-line analysis of the level of professional skills of arc welding specialists. Interactive electric welding laboratory allows accelerating the process of training in welding technologies (and reducing the cost, respectively), improving the quality of specialist training due to application of modern interactive technologies when learning practical skills of the welding process. Welder's trainer is a unique local development of PWI specialists.

The trainee is able to conduct preliminary trials and welding process under the instructor's guidance for familiarization with the training facility. Then test welding can be performed for assessment of welder's professional level. Various calculation procedures are used for calculation assessment for each welding process type. Welder's training and testing are performed for real processes of MMA, MIG/MAG and TIG welding.

The laboratory includes: tabletop personal computer, tabletop block of technological interface with specialized electrode holder, welding table; and welding power source.

Main functions of the trainer:

• entering the task for selected welding process (from the panel or earlier saved task file);

• measurement, processing, calculation and real-time representation of the following welding process parameters and auxiliary signals: welding current; arc voltage; arc length; welding speed; heat input; horizontal angle of electrode inclination (turning along the arm axis); vertical angle of electrode inclination (up and down movement of the wrist); deposit cross-section; deposited metal weight; gas flow rate; electrode position on the sample; filler wire feed signal; calculation assessment of the quality of performed welding (several welding passes can be performed within one assessment);

• viewing graphs of recorded welding processes after assessment;

• preservation in the form of operating system files of tasks for assessment of various kinds of welding processes for fast setting up of the training facility for a specific process;

• preservation in the form of operating system files of resulting data of assessment for possible subsequent analysis.

The training facility can be used in training establishments, specializing in arc welders' training; large welding enterprises for certification or re-certification of welder personnel or in a specialized organization involved in supervision, training or re-training of arc welding specialists.